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Comparing physical measures and mechanical cracking products of 'Nonpareil' almond (*Prunus dulcis* [Mill.] D.A. Webb.) with two advanced breeding selections

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Abstract

Kernels of 'Nonpareil' almond and advanced breeding selections 23.5–16 and 23–122 were evaluated for similarities and differences in commercially important kernel characteristics. These three almond types did not differ in kernel mass, kernel length and width, nor in kernel color coordinates, luminosity and hue. 'Nonpareil' kernels were observed to be significantly ($p \leqslant 0.05$) thicker than kernels of 23.5–16 and 23–122. Chroma value of 'Nonpareil' kernels was significantly higher ($p \leqslant 0.05$) than that of 23–122, but did not differ from that of 23.5–16. Bulk in-shell samples of the three almond types were then compared after a mechanical cracking treatment using identical roller settings in a research-sized commercial cracking machine. Sticktight content varied significantly ($p \leqslant 0.01$) amongst the three almond types prior to cracking bulked samples. The cracking treatment significantly reduced ($p \leqslant 0.01$) sticktight content in each of the almond samples and a significant interaction ($p \leqslant 0.01$) was observed between almond types and cracking treatment with regard to sticktight content. 'Nonpareil' and 23.5–16 did not differ in sticktight content either prior to or after the cracking treatment. The three almond types varied significantly ($p \leqslant 0.05$) in the various categories of edible kernels (whole, double, scratched, broken & chipped) after the cracking treatment.

Keywords: Chroma; Crackout; Doubles; Kernel; Sticktight

1. Introduction

Over 250,000 ha of almond (*Prunus dulcls* [Mill.] D.A. Webb.) are planted in California orchards and annual production has provided more than half the world's commercial almond supply in each of the last 20 years. Nearly 40% of the planted acreage is comprised of the cultivar 'Nonpareil' (Anonymous, 2002a). 'Nonpareil' is the preferred almond of commerce for many of the world markets. Producers enjoy the high yield potential of this old cultivar and the high percentage of kernel-to-nut (crackout). On the other hand, 'Nonpareil's shell is incompletely sealed allowing entry to the kernel by naval orangeworm and peach twig borer (Gradziel & Martínez-Gómez, 2002; Soderstrom, 1977). The cultivar is also prone to a genetic disorder known as noninfectious bud-failure (Kester & Jones, 1970), which is most pronounced in the warmer and highly productive growing regions (Kester & Hellali, 1972). Despite these drawbacks, 'Nonpareil' continues to be planted at a higher rate than other available cultivars (Anonymous, 2002b).

Like the vast majority of almond cultivars in California, 'Nonpareil' is self-incompatible and requires another cultivar for pollination and to ensure adequate yield. While successful pollenizers must bloom with 'Nonpareil'

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Fig. 1. Representative kernel samples of 'Nonpareil' almond (center) with pollination inter-compatible advanced breeding selections 23.5–16 (left) and 23–122 (right).

to accomplish pollination, they must also be harvested separately to ensure that no mixing of nuts occurs. Mixing of dissimilar kernels from two or more distinct cultivars typically lowers the financial return to the grower. To date, only the seldom planted 'Kapareil' cultivar has been widely accepted by the almond marketing standards and is generally included within the 'Nonpareil' Marketing Group. Yield of 'Kapareil' has been less than optimal and plantings with 'Nonpareil' have been limited to date (Micke et al., 1999). Investigations continue to identify new cultivars of almonds that more precisely match the characteristics of 'Nonpareil', and could be blended and marketed with it.

The Agricultural Research Service's *Prunus* breeding program in Parlier, CA is currently evaluating several advanced almond selections for the possibility of being combined with 'Nonpareil' at harvest. Advanced almond selections 23–122 and 23.5–16 both bloom with and are capable of cross-pollination with 'Nonpareil'. Harvest of these two advanced selections can occur simultaneously with 'Nonpareil'. Similarities between the kernels of these three almond types are visually evident (Fig. 1) and samples of mixed kernels are difficult to distinguish from single-type kernel samples. While yield has not yet been fully evaluated, the yield potential of both selections appears adequate to be included in new orchard plantings with 'Nonpareil'. This study has two specific objectives: (1) document the important carpological characteristics of selections 23.5–16 and 23–122 relative to those of 'Nonpareil'; and (2) determine kernel quality and cracking products after a mechanical cracking treatment of bulk in-shell samples using commercially available almond cracking machinery. Determining the degree of similarity between the advanced almond selections and 'Nonpareil' is paramount to further developmental work with these selections.

2. Materials and methods

2.1. Orchard conditions

Almond trees utilized in this study were grown at the San Joaquin Valley Agricultural Sciences Center in Parlier, CA. Utilized trees were among seven almond cultivars and advanced breeding selections planted in a randomized complete block trial. Ten trees of each almond were propagated onto 'Nemaguard' peach seedling rootstock and were in their sixth growing season during the study.

After hull split, almonds of 'Nonpareil', 23–122 and 23.5–16 were knocked from the trees with large rubber mallets. The harvest of all trees was accomplished on the same date. Almonds were allowed to air-dry where they fell on the orchard floor for three days, raked into piles, screened to remove loose materials and collectively placed in plastic bins. Almonds were then stored in an uncooled greenhouse for approximately 30 days prior to obtaining samples to equalize the moisture content of the three bulked harvests.

2.2. Almond samples used in the study

Kernel dimensions and mass of the three almond types were determined using whole undamaged kernels from randomly selected nuts in the bulk samples. Obvious double-kernelled almonds (doubles) were purposefully excluded in these samples. A total of 44 kernels were used per almond type to calculate kernel mass, dimensions and kernel color parameters.

A second set of samples was used in the almond cracking study. Five 700 g samples were randomly withdrawn from each of the three bulk samples. The 700 g samples were examined carefully for foreign matter and sticktights (an in-shell almond with the hull adhering tightly to the shell). Foreign matter was quantified and removed. Sticktights were counted and then returned to the 700 g samples prior to cracking. Since sticktights are particularly difficult to successfully crack, there was interest in determining the ability of the cracking treatment to successfully break apart sticktights from each of the almond types. After cracking, samples were again examined and evaluated for their content of whole kernels as well as the proportions of other classes of edible nutmeats (double kernels, scratched kernels, broken and chipped kernels) and uncracked nuts. Sticktights were again quantified after sample cracking and the proportion of sticktights that were successfully cracked was noted.

2.3. Instrumentation and analysis

A research-sized commercial almond cracking unit was utilized in the study. The unit, designated as Model CR06, was manufactured by Lewis M. Carter Manufacturing Company, Inc. (Ripon, CA) and consisted of a $0.06\ m^3$ surge hopper mounted atop a syntron light-capacity electromagnetic vibrating feeder (FMC Corporation, Homer City, PA) that fed into the cracking head (Fig. 2). Rubber rollers of 15 cm diameter that revolved at differing speeds (310 RPM vs. 194 RPM) provided the shearing action to break apart the hulls and shells from the kernels. The distance between the rubber rollers could be manually set to accommodate nut minimum dimensions from 4 mm to 21 mm. Part of the bulked 'Nonpareil' sample was used for initial calibration of the cracker prior to use on the 700 g samples. The unit's rubber rollers were set to minimize both uncracked nuts and damaged/broken kernels for 'Nonpareil' almond samples. Empirical testing indicated that a minimum gap dimension of 7.98 mm between rubber rollers should be used at the onset of cracking to minimize damage to the 'Nonpareil' samples as well as maximize the yield of whole undamaged kernels in the year the study was conducted.

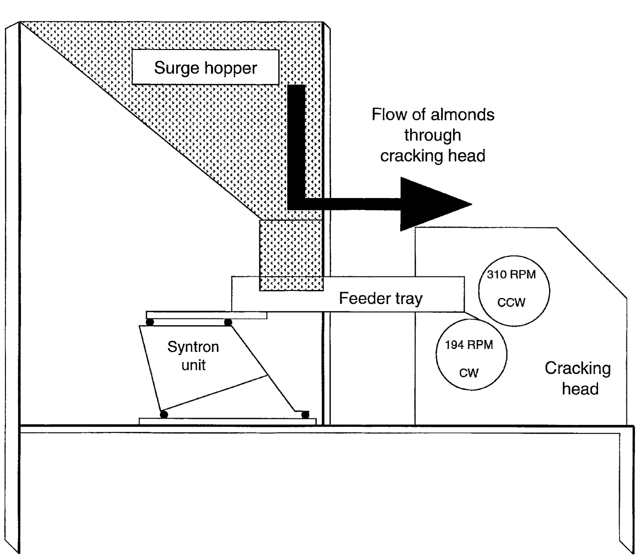

Fig. 2. Schematic illustration of mechanical almond cracking unit.

Dimensional measurements of kernels were made with a digital caliper (Starrett, Athol, MA). Luminosity, chroma and hue measurements of kernel pellicles were accomplished using a Minolta Chroma Meter CR-200 equipped with an 8 mm aperture (Minolta Corp., Ramsey, NJ). Luminosity is representative of the vertical axis (L^*) of a color solid with percentage values ranging from 0 (black-no reflectance) to 100 (white-complete reflectance). Luminosity measurements provide information on the degree of lightness or darkness associated with pure chromatic colors. Chroma and hue values are both calculated from color solid axes a^* and b^*. At any given plane on the color solid representative of an L^* value, a^* is a positive or negative coordinate perpendicular to L^*, and representative of the purplish-red to bluish green axis. Coordinate b^* is expressed as a positive or negative value on the same plane of the color solid that represents the yellow to blue axis. Hence, colors in the color solid near the vertical axis L^* represent shades of grays, while as a^* and b^* increase away from L^* in absolute value, chromaticity also increases. Chroma (C^*) and Hue (H°) are calculated from the following formulas (McGuire, 1992):

$$C^* = [(a^*)^2 + (b^*)^2]^{1/2}$$
$$H^\circ = \arctan(b^*/a^*)$$

2.4. Experimental design and statistical analyses

A completely random design (CRD) was used to examine cracking products and kernel characteristics. Single-factor analyses of variance (ANOVA) were used to analyze kernel mass, length, width and thickness dimensions, kernel color coordinates (luminosity, chroma and hue), and weights of whole, double, scratched, broken & chipped and unbroken nuts, along with percentage of whole and edible nutmeats. A repeated measures ANOVA was performed on pre- and post-cracking sticktight content of the bulked almond samples for the three types of almonds. Levene's homogeneity of variance test was performed to check for data transformation necessity. If a significant F-test statistic was obtained from an ANOVA at $p \leqslant 0.05$, a Duncan's new multiple range test was used as the multiple comparison procedure to determine differences among the almond accessions.

To determine if kernel dimension differences were present between the three types of almonds, separate simple linear regression equations were calculated for kernel mass as a function of kernel length, width, or thickness, for each of the almonds. General linear model (GLM) F-tests for full and reduced models were used to determine if there were any overall differences between the equations in question for each almond (Neter, Wasserman, & Kutner, 1990). If a significant GLM F-test was obtained, indicating that at least one of the almond equations was different from the rest, distance metrics were used as a multiple comparison test for determining which equations were different from the others, based on slope and intercept differences (Palmquist, 1993; Palmquist, Bagchi, Young, & Davis, 1993). PROC REG and PROC GLM were the statistical procedures used for most of the analyses (SAS Institute Inc, 1999).

3. Results and discussion

3.1. Comparison of physical measures

Mass and dimensional data for kernels of the three almond types are presented in Table 1. 'Nonpareil' kernels tended to be slightly heavier and longer than either 23.5–16 or 23–122, but differences were not significant. Kernels of 23–122 tended to be wider than either 'Nonpareil' or 23.5–16 although there were no significant differences noted. 'Nonpareil' kernels were significantly thicker ($p \leqslant 0.05$) than either of the other almonds which did not differ in kernel thickness. Kernels of the three almonds were quite similar in pellicle color and did not differ significantly in pellicle luminosity or hue. Pellicle chroma of 'Nonpareil' was significantly ($p \leqslant 0.05$) higher than that of 23–122; pellicle chroma of 23.5–16 was intermediate. The current USDA Standard (§51.2116) for all grades of shelled almonds grown in California states that pellicle color shall not be considered in distinguishing similarity or difference between cultivars (Anonymous, 1997). Hence, the differences noted in pellicle chroma between the three almonds would not, in itself, limit the mixing of these accessions in a combined harvest.

Simple linear regressions were conducted to examine the relationships between kernel mass and kernel length, width and thickness. These regression equations, associated R^2 values and slope comparisons are presented in Table 2. Accession 23–122 gained length at a significantly ($p \leqslant 0.01$) lower rate as mass increased when compared with 'Nonpareil' kernels. Accession 23.5–16 did not differ from either 'Nonpareil' or 23–122. 'Nonpareil' kernels became broader at a significantly ($p \leqslant 0.01$) higher rate as kernel mass increased when compared

Table 1
Kernel mass, kernel dimensions and kernel color coordinates (average ± standard deviation) for 'Nonpareil' almond and two advanced almond selections

Almond type	Kernel mass (g)	Kernel dimensions (mm)			Kernel color coordinates		
		Length	Width	Thickness	Luminosity	Chroma	Hue
Nonpareil	0.94 ± 0.14	21.7 ± 1.4	11.7 ± 0.8	7.6 ± 0.4 a[a]	45.8 ± 2.0	35.5 ± 2.0 a	66.3 ± 1.5
23.5–16	0.88 ± 0.12	21.5 ± 1.4	11.7 ± 0.7	7.3 ± 0.4 b	45.8 ± 2.9	34.6 ± 1.6 ab	66.6 ± 1.2
23–122	0.92 ± 0.12	21.2 ± 1.3	11.9 ± 0.7	7.3 ± 0.4 b	46.4 ± 2.2	32.5 ± 1.1 b	66.9 ± 1.5

[a] Means followed by the same letter within a column are not significantly different at the 0.05 α level according to a Duncan's Multiple Range test.

Table 2
Regression equations, coefficients of determination and slope comparisons for kernel mass as functions of kernel length, width or thickness for three types of almond

Almond type	Regression equation	R-squared	Slope comparison[a]
X = Kernel length			
Nonpareil	$Y = -1.051 + 0.092X$	0.82	b
23.5–16	$Y = -0.876 + 0.082X$	0.85	ab
23–122	$Y = -0.649 + 0.074X$	0.65	a
X = Kernel width			
Nonpareil	$Y = -0.978 + 0.164X$	0.79	b
23.5–16	$Y = -0.882 + 0.151X$	0.78	a
23–122	$Y = -0.895 + 0.152X$	0.75	a
X = Kernel thickness			
Nonpareil	$Y = -0.299 + 0.163X$	0.0005	
23.5–16	$Y = -0.509 + 0.191X$	0.30	
23–122	$Y = 0.148 + 0.106X$	0.14	

Kernel mass = $\beta_0 + \beta_1 X$.
[a] Within a kernel dimensional grouping, slope comparisons having the same letter do not differ significantly according to post-hoc distance metric comparisons at the 0.01 α level.

with almonds 23.5–16 and 23–122. No significant differences were noted in rates of width change per unit of kernel mass between 23.5–16 and 23–122. No significant differences were noted in rate of change in kernel thickness per unit kernel mass among the three almond types. Kernel thickness regressed upon kernel mass yielded low coefficients of determination as compared with kernel length and width. As explained by Kester and Asay (1975), kernel thickness changes are not as proportional relative to changes in kernel mass as compared with either kernel width or kernel length changes.

3.2. Cracking study

Bulked in-shell samples used for the cracking study did not differ significantly in pre-cracking weight after removal of foreign matter (data not presented). However, sticktight content varied significantly ($p \leqslant 0.01$) in the pre-crack samples (Table 3). Sticktight content of 23–122 pre-crack was significantly higher ($p \leqslant 0.01$) than either 'Nonpareil' or 23.5–16 which did not differ. The significant ($p \leqslant 0.01$) interaction between almond type and cracking treatment (pre-crack vs. post-crack) was due primarily to higher numbers of sticktights remaining in samples of 23–122 post-crack. After cracking the bulked samples and recounting uncracked sticktights, no significant ($p \leqslant 0.01$) differences in uncracked sticktights were observed between 'Nonpareil' and 23.5–16. A tabulation of pre-and post-cracking results for sticktight content is presented in Table 3.

Differences were noted in each of the four classes of edible nutmeat kernels between the three almond types (Table 4). While no significant differences existed between 'Nonpareil' and 23.5–16 for weight of whole undamaged kernels, 23–122 had a significantly ($p \leqslant 0.05$) lower amount than the other two types. Selection 23–122 had the highest amount of double kernels, 'Nonpareil' was intermediate and selection 23.5–16 had the lowest. The United States grade designation of "US Fancy" limits double kernel content to no more than 3.0% allowable, by weight (Anonymous, 1997). A higher content of doubles lowers the profit potential of almond growers because lower prices are received for almonds fitting the standards of less prestigious grades. Scratched

Table 3
Repeated measures ANOVA on pre- and post-cracking sticktight content of bulked almond samples for Nonpareil, 23–122 and 23.5–16

Source	*df*	MS	*F*
Almond type	2	1051.4	46.7**
Sample (type)	12	22.5	1.9
Cracking treatment	1	7489.2	634.7**
AT × CT	2	359.1	30.4**

Main effect 'almond type'

Almond type	Sticktight no.
Nonpareil	19.7
23–122	37.1
23.5–16	19.0

Main effect 'cracking treatment'

Treatment	Sticktights
Pre-crack	41.1
Post-crack	9.5

Interaction effect of 'almond type × cracking treatment'

Almond type	Cracking treatment	Sticktights
Nonpareil	Pre-crack	31.6 b[a]
	Post-crack	7.8 d
23–122	Pre-crack	59.8 a
	Post-crack	14.4c
23.5–16	Pre-crack	31.8 b
	Post-crack	6.2 d

[a] Means followed by the same letter within a column do not differ significantly at the 0.01 α level according to a Duncan Multiple Range test.

Table 4
Weights of almond kernel classes after cracking, unbroken nut weight and percentages of almond kernels from 700 g almond samples

Almond type	Edible nutmeat kernels (g)				Unbroken nuts (g)	Percentage whole[a]	Nutmeats edible[b]
	Whole	Double	Scratched	Broken and chipped			
Nonpareil	171.5 a[c]	6.4 b	3.6 a	12.9 b	21.1	88.2 b	28.9 a
23–122	117.6 b	17.9 a	0.9 b	29.4 a	20.7	71.0 c	24.2 b
23.5–16	163.8 a	0.2 c	0.4 b	5.7 c	19.1	96.3 a	25.5 b

[a] Represents the percentage of edible nutmeat kernels that are whole and undamaged.
[b] Represents the summation of all edible nutmeat kernel classes relative to the sample weight with foreign matter removed.
[c] Means followed by the same letter within a column do not differ significantly at the 0.05 level according to a Duncan Multiple Range test.

kernels were significantly ($p \leqslant 0.05$) higher in 'Nonpareil' than in the other two almond types. Broken and chipped kernels were highest in 23–122, intermediate for 'Nonpareil' and lowest in 23.5–16 ($p \leqslant 0.05$). No significant differences existed between the three almond types for the quantity of unbroken nuts after the cracking treatment. The percentage of whole nutmeats ranged from a high of 96.3% (23.5–16) to a low of 71.0% for 23–122. Whole nutmeat percentages were significantly different ($p \leqslant 0.05$) with 23.5–16 being the highest, 'Nonpareil' being intermediate and 23–122 having the lowest percentage of whole nutmeats. Lastly, Nonpareil's percentage of edible nutmeats was significantly ($p \leqslant 0.05$) higher than either 23–122 or 23.5–16.

4. Conclusions

Almond kernels offered for sale under the 'Nonpareil' Marketing Classification must match specific requirements imposed by individual almond handlers in order to be sold as 'Nonpareil'. Results obtained in this study indicated only small carpological differences between 'Nonpareil' almond and almond selections 23–122 and 23.5–16. No differences were observed between the three almonds for kernel weight, length and width. Luminosity and hue values of the pellicle similarly did not differ between the three types of almond. Sticktight content and the percentage of double kernels were found to be higher in 23–122 as compared to 'Nonpareil' and 23.5–16. The research-sized almond cracking unit utilized in this study effectively reduced and removed sticktights from all three types of almonds with the same roller settings. Thus, it appears that these almonds could be cracked together from a combined harvest without preferentially damaging kernels of any one accession. While interpollination amongst these three almonds occurs and harvests of the almonds can occur simultaneously, formal yield trials would still be necessary in order to provide data to growers and nurserypersons to demonstrate that the advanced almond selections warrant propagation.

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